280m Near Detector Research for T2K Neutrino Oscillation Experiment

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May 11, 2004

Dr. Randy Lewis,
Physics Academic Advisor,
Cooperative Education

Dear Dr. Lewis,

I have completed the first half of a double work term at TRIUMF under
the supervision and guidance of Dr. Akira Konaka and Dr. Stanley Yen.
The seventeen week term, which began on January 5, 2004 and ended on
April 30, 2004, was the second of five work terms I plan on completing. I
am now submitting my work term report for evaluation.

I spent my work term as a research assistant with the Neutrino Group.
During my term I was involved with the research and development of a near
detector that will be built in Tokai, Japan as part of a project to study
neutrino oscillations. My goal was to overcome some of the design
challenges associated with the near detector which provided a suitable topic
for my work term report.

I have prepared a report, entitled "280m Near Detector Research for T2K
Neutrino Oscillation Experiment," describing the experiment in general, the
design challenges of the near detector and the results of the research to date.

Sincerely,
Jenna King
ID# 200221752

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Work Term #2

May 11, 2004

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Abstract

Triumf's Neutrino group is working on an international collaboration to study neutrino oscillations in an attempt to understand more about the nature and properties of neutrinos. An overview of the set up of the experiment is provided with specific focus on a single detector, the 280m near detector. It will be used primarily to determine the composition and stability of the particle beam coming from the JHF proton accelerator after hitting a carbon target. The near detector posed many design problems such as finding a liquid solution which scintillates but is composed mainly of water, to embed the solution into some sort of gel to prevent leaks and to study the effects of time on the wavelength shifting fibres that are going to be used to measure the scintillation light. Commercially available liquid scintillators InFlow 2:1 and QuickSafe A were found to be suitable for the purposes of the detector. Their performance improved upon the addition of a small amount of a non-ionic surfactant called Triton X-100. Carrageenan powder produced the best results as a gelling agent and the aging tests have been inconclusive thus far.

1 Introduction

1.1 TRIUMF

Canada's national laboratory for particle and nuclear physics began as a collaboration between three British Columbia universities in 1971, with the original acronym being TRI-University Meson Facility. Home of the world's biggest cyclotron, TRIUMF has since grown in both size and reputation to include five universities, six associate universities and collaborators from across the globe [1]. TRIUMF is now one of the world's leading subatomic research facilities. Covering nearly all aspects of nuclear and particle physics, several research groups work alongside each other within the facility, each with their own specific goals and focus. TRIUMF's Neutrino Group is currently involved in an international collaboration with fifty other groups on what is called the Tokai-to-Kamioka project (T2K).

1.2 Neutrinos and Neutrino Oscillations

Part of the reason the nature and properties of neutrinos are so difficult to determine is that while they do experience weak nuclear forces, neutrinos do not experience the strong or electromagnetic interactions that are seen with quarks. The absence of these strong and electromagnetic interactions allow the neutrinos to travel great distances without interacting with other

matter. When the iron core of a massive star collapses in on itself, causing electrons to be absorbed by protons, supernova neutrinos are emitted which travel great distances. Neutrinos are also created in the fission reactions in the sun, there are relic cosmological neutrinos that originated just fractions of a second after the creation of the universe and there are ultra-high energy cosmic neutrinos caused by some presently unknown violent process.

Since neutrinos can pass through stars and planets and reach the earth from such huge distances they may hold valuable information about the structure and origin of our universe. This will enable us to look for evidence of a Grand Unified Theory (GUT) relating all forces. There may also be information on the GUT time scale where electromagnetic, strong nuclear and weak nuclear forces would have been unified. On this sort of time scale we may see evidence of the theorized proton decay, thought to occur with a lifetime on the order of 10^{35-37} years.

Evidence that neutrinos oscillate from one flavour to another was first supported by the Super-Kamiokande collaboration in 1998. Their findings were later verified by the Sudbury Neutrino Observatory (SNO). Neutrino oscillations are quantum mechanical in nature, with neutrinos exhibiting both wave and particle properties. Like a wave packet, the neutrino is dectectable as a particle but consists of waves that are capable of interefering. What we observe is a projection of the quantum mechanical complex space into real space. The flavour and phase of the neutrinos are not well defined. When we detect a certain flavour of neutrino, we are observing that specific flavour eigenstate. The same way that light can be linearly and circularly polarized, neutrinos have both flavour and mass eigenstates.

Examining only electron (ν_e) and muon (ν_μ) neutrinos, a travelling neutrino of electron flavour can pass through two mass eigenstates, ν_1 and ν_2 corresponding to different masses (m_1 and m_2) and therefore velocities causing a phase difference in the waves. This phase difference will cause interference and eventually the electron neutrino will change flavours and become a muon neutrino. The muon neutrino will experience the same thing and oscillate back to an electron neutrino, each oscillation occuring over a distance of several hundred kilometers. This process is analogous to a losely coupled pendulum where an oscillation of one side will gradually work its way over to the other side and back or the way beats are heard when two close frequencies are sounded simtaneously. By observing the oscillation pattern, we will not be able to determine the absolute mass of the neutrinos but rather the mass difference (Δm_{12}) between the two eigenstates ν_1 and ν_2. This mass difference, however, implies that the neutrinos must have an absolute mass of some magnitude. The Mixing Angle, θ, or the angle be-

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tween ν_e and ν_1 in complex space is another desired quantity. It represents a complex rotation in a two dimensional complex plane and is a measure of the degree to which the different neutrino flavour eigenstates mix together to form the observed mass eigenstates.
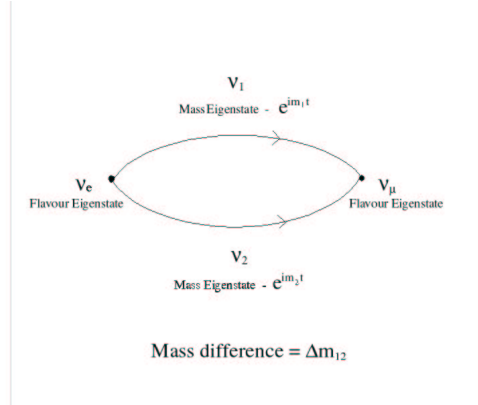

Figure 1: Eigenstates
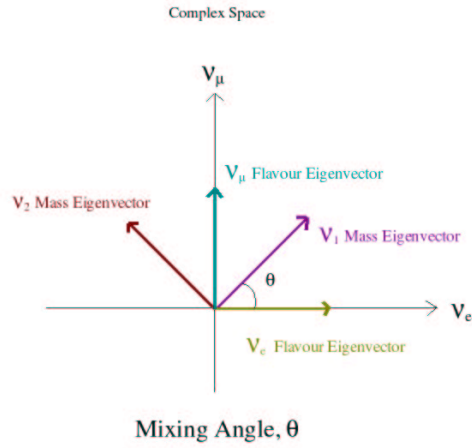

Figure 2: Eigenvectors and Mixing Angle in Complex Space

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix} \tag{1}$$

1.3   Liquid Scintillation and Wavelength Shifting

Figure 3: Fluorescent Gel in UV light

Certain materials, when exposed to ultraviolet light or ionizing radation fluoresce or scintillate. Most organic scintillators contain Benzene rings. A liquid scintillator consists of a solvent and at least one solute, often called a fluor becaues of its fluorescent properties. The ionizing radiation excites the molecules of the solvent and the energy is transferred to the fluor, which emits a photon.

These photons are most commonly detected with a photomultiplier tube (PMT); however, often the wavelength of this light is too short for the PMT to be sensitive to it so there is often a second fluor added to the solution to act as a wavelength shifter. The light energy from the primary solute is absorbed by the secondary solute which can then emit a photon at a longer wavelength more suited to the most sensitive region of wavelengths detected by the PMT. A commonly used primary scintillator is 2,5-diphenyloxazole (PPO) which emits most of its light at a wavelength of approximately 416nm and a typical secondary fluor would be 1,4-di-2-(5-phenyloxazolile-benzene) (POPOP) which shifts the wavelength to around 423nm [2].

In order to transfer the scintillation light over a distance of several meters, wavelength shifting (WLS) fibre is used. The scintillation light is shifted, trapped, and transfered through the WLS fibre. The specific fibre we are looking at is 1mm in diameter and has a plexiglass-like coating around a polystyrene core. Wavelength shifting chemicals similar to PPO and POPOP are suspended in the plastics. The coating has an index of refraction of 1.42 and the core has an index of refraction of 1.58.

This difference in indices enables a significant fraction of the light that is generated by the fluors in the WLS fibre to travel all the way down the fibre by means of total internal reflection. The fibre can be designed with the correct wavelength shifters such that the light emitted is in the region of highest sensitivity for the PMT.

2 T2K Project

2.1 Purpose

In general, the goal of T2K is to study neutrino oscillations. Researchers can look for the appearance of electron neutrinos, ν_e, and the disappearance of muon neutrinos, ν_μ. These appearances and disappearances can lead to a better understanding of neutrino oscillations. By observing an entire oscillation pattern, more knowledge can be gained about neutrinos and how they behave. The depth of the oscillation pattern can give us the mixing angle, a quantity important to understanding how neutrinos oscillate, and the position of the dip will indicate the difference in mass between the two flavours between which the neutrino is oscillating.

2.2 Set Up

The JHF proton accelerator in Japan uses a series of different types of accelerators to achieve a proton energy of 50GeV. After breaking down molecular hydrogen into atomic hydrogen and removing the electrons, the resulting hydrogen ions are sent through a linear accelerator capable of accelerating the positively charged paricles to an energy of 400MeV. The high-intensity beam is then directed through two synchrotrons, boosting the energy to first 3GeV and finally as high as 50GeV. Kicker magnets then deflect these high energy protons towards the desired target.

As a consequence of the finite time it takes to accelerate a group of injected particles to the required velocity, the synchrotron produces a 5 microsecond pulse of beam every 3.3 seconds. The JHF neutrino target is an 80cm long carbon based target. Graphite is used as the main component and the target will be cooled with either water or helium. When the protons hit the carbon nuclei, pions and kaons are produced. The kaon reaction is far less frequent, making up only five to ten percent of the beam.
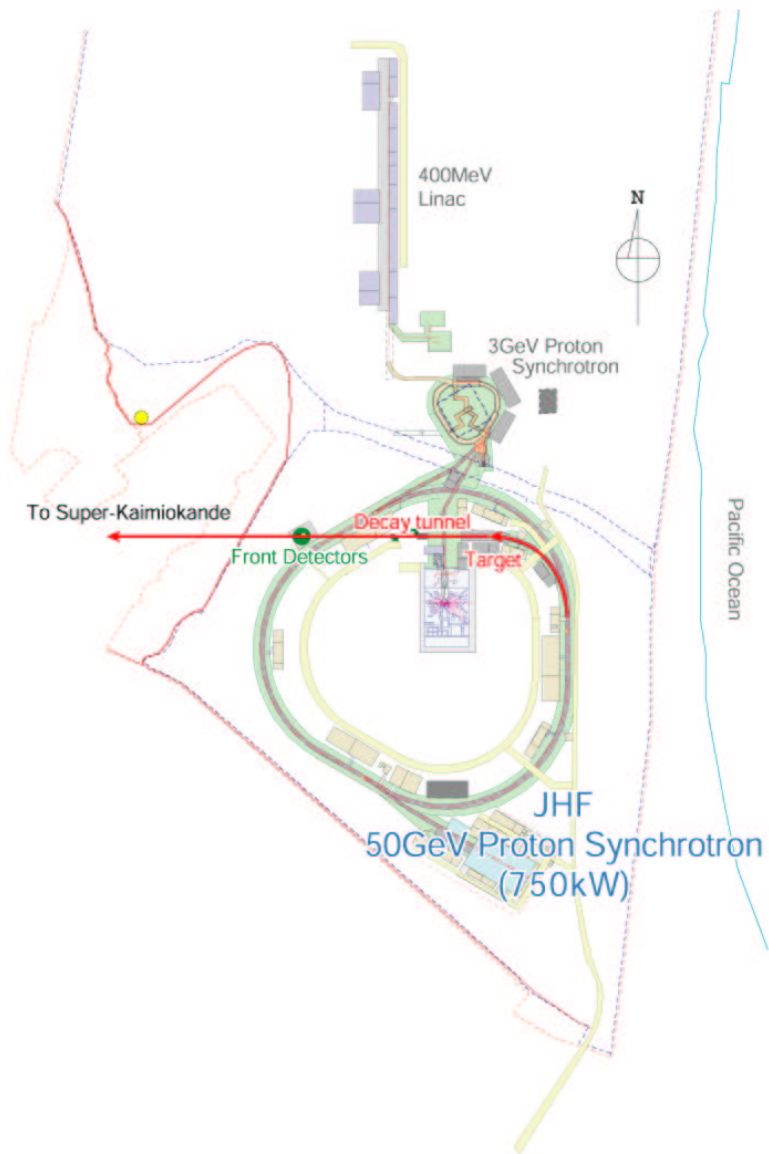
$$p + p \rightarrow p + n + \pi^+ \tag{2}$$

Figure 4: Proton Accelerator Layout [3]

The resulting high-energy beam is focused by another set of magnets called Horns into a 100m long decay pipe. While travelling the 100 metres through the pipe, the pions and kaons will decay into muons and muon neutrinos with pion decay being the primary mechanism for producing muon neutrinos.

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \tag{3}$$

It is this pion to muon decay which produces the muon neutrinos desired for study. There is a beam dump at the end of the decay pipe to stop all the charged particles except for neutrinos and some small fraction of muons. Upon exiting the beam dump there is a two dimensional array of diamond sensors positioned around the beam axis used to determine the direction of the particles. Since the beam will travel many kilometres from this point, a precise knowledge of the beam's initial direction becomes very important in positioning the detectors. Finally, the beam of neutrinos will pass a near detector at 280m primarily for normalization purposes and continue on to its final destination of a 50kton water-Cerenkov detector. The far detector, Super-Kamiokande, is 295km away and is located inside of a mountain with 1000m of overburden in an attempt to shield the detector from cosmic rays. There is still approximately one cosmic ray detected per second.

2.3 Near Detector

2.3.1 Purpose

The purpose of the 280m near detector, which will not be found directly on the axis of the decay tunnel, is to determine the precise direction, energy, flux, and composition of the neutrino beam. This data enables researchers to predict what should be observed at the far detector. The near detector will be able to predict both the signal muon neutrinos, ν_μ, from the pion decay as well as the background electron neutrinos, ν_e. The background contamination of ν_e is present in the beam because a small fraction of pions and muons will decay into positrons and two neutrinos.

$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e \tag{4}$$

The difference in the spectra will be as great as $10 - 30\%$ between the near and far detectors due to the fact that the neutrinos will appear to be coming from a point source by the time they reach the far detector but the physical size of the decay pipe will affect the off-axis angle of the near detector. This far/near ratio correction can be taken into account when analyzing data. An example of a way to further reduce this problem would

be to have a third detector at 2km. At this distance the far/near ratio correction is reduced to a few percent but the funding for a 2km detector is not approved at this point.

2.3.2   Design Outline

The near detector is going to be a fine-grained scintillation detector. The scintillation light will be read out by a grid of WLS fibres throughout the volume of the near detector. A water-based detector is desired to simplify comparisons with the far detector and eliminate the uncertainties associated with having a different nuclear target. For the case where water is the main component of the detector, neutrinos would collide with the oxygen (O^{16}) nuclei, more specifically the neutrons, to produce protons and muons.

$$\nu_\mu + n \rightarrow \mu^- + p \tag{5}$$

Having a scintillation detector will allow us to detect both the recoil proton and the muon but some of the protons are reabsorbed and never make it out of the nucleus to be detected, an uncertainty that is minimized if both detectors are made of the same type of nuclei. Having an off-axis detector also adds to the sharpness of the neutrino energy spectrum. When the pion decays, it emits a neutrino and a muon travelling opposite directions. As the energy of the pions increase in the lab reference frame, the neutrinos that happened to be travelling forward along the axis of the beam ($\sim0°$) will experience an increase in energy as well, but the neutrinos emitted in the opposite direction ($\sim180°$) will experience a decrease in energy. The result is a point between 0°and 180°where the energy of the neutrinos will remain relatively constant regardless of the initial pion energy. This is the best position for the detector, providing an energy spectrum that is narrow and well-defined.

2.3.3   Main Challenges

The first of three major challenges in designing the near detector is finding a suitable scintillator. As previously mentioned if it is possible for the near detector to use a water target, as does Super-K, the systematic error associated with nuclear absorption and nuclear Fermi motion will be minimized. However, an oxygen-based water target, while more than appropriate for a Cerenkov detector, does not lend itself easily to scintillation detection since water and oxygen are well known quenchers of scintillation light [4]. The light yield must be great enough to account for light lost while travelling

down the fibres. There must be sufficient light output throught the WLS
fibres for any data obtained to be meaningful. Even with 100 tons of liq-
uid scintillator, only a few neutrino interactions per second are expected.
Another concern with the design of the 280m detector, as with most liquid
detectors, is leaking. To read out the light yield from the WLS fibres they
must run right out of the detector, creating many opportunities for the liq-
uid scintillator to leak through the joints. The third major thing to consider
is that the detector is going to be in operation for at least a decade and on
that time frame the effects of aging on both the scintillator and the WLS
fibre becomes a very real concern. Any loss of light yield over time could
leave researchers with a useless detector or expensive repairs long before
they are finished collecting data.

3   Near Detector Research

3.1   Apparatus

Figure 5: Loading Scintillation Counting Vial into Apparatus

The apparatus used in the experiments allows us to create 22ml sam-
ples in commercial glass scintillation-counter vials. The entire vial can be
inserted into a black, plexiglass tube and screwed closed, blocking all out-
side light. One inside end of the tube has UV transparent plexiglass and a
PMT. When a sample is inside the closed tube a high voltage power supply

connected to the PMT is turned on and a Cobalt-60 source, which emits two gamma rays of 1.17 and 1.33 MeV, is placed on the lid. The resulting scintillation light is then detected by the PMT. To minimize the amount of light lost, the vial is completely covered inside the apparatus by a sheet of aluminized mylar which will reflect nearly all light into the PMT [Appendix A]. The software ROOT is used to start and stop the collection of data and produces a histogram of the number of counts observed versus the ADC channel for each run. ROOT also provides the number of absolute counts observed each time.

3.2 Liquid Scintillator and Gel Tests

Most commercially available liquid scintillators have poor solubility in water as most scintillating organic compounds share that property. Two commercial scintillators, InFlow 2:1 and QuickSafe A, were designed to test aqueous samples and therefore have a considerably higher than average solubility in water. These two scintillators are being tested for our purposes. By using our specially designed apparatus, we are able to test the light output of various concentrations of water mixed with either scintillator and note whether or not there is a recognizable Compton edge from the gamma source.

3.2.1 InFlow 2:1

Inflow 2:1, made by IN/US Systems [5], is 60-70% 2-isopropyl xylene mixed with 30-40% of a non-ionic surfactant to improve its water-solubility. By mixing samples with concentrations of water ranging from $10 - 50\%$ in our 22ml scintillation counting vials, it was found that the more water that is added, the whiter and cloudier the solution becomes. We are able to recognize a Compton edge with most concentrations. By adding another non-ionic surfactant called Triton X-100 [6] the transparency is improved, the Compton edge becomes sharper and there is an increase in the total number of counts observed [Fig:6,7]. The total amount of Triton X-100 needed for the improvement was typically 1 to 2ml in a total volume of about 22ml. It was possible that not only the scintillator was diluted by the water, but also the secondary fluors used to shift the light to the correct wavelength so we dissolved one gram of a PPO/POPOP mix into 50ml of Triton X-100. Using a millilitre or two of this Triton X-100/PPO/POPOP mix instead of pure Triton X-100 showed an increase in the number of counts seen which does suggest the secondary fluors were too diluted to work efficiently. All histograms are the number of counts plotted against the ADC channel.
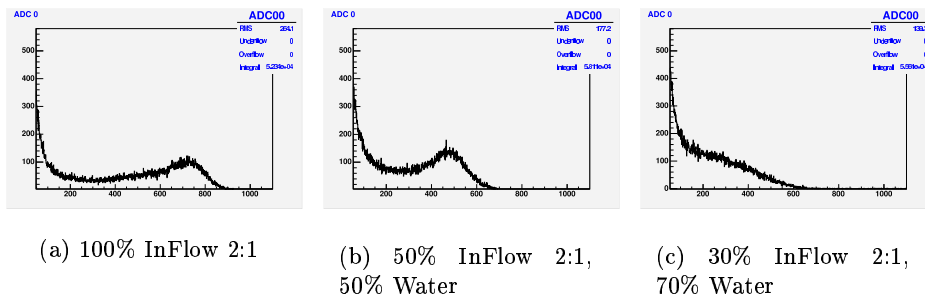
(a) 100% InFlow 2:1

(b) 50% InFlow 2:1, 50% Water

(c) 30% InFlow 2:1, 70% Water

Figure 6: InFlow 2:1 Spectra

(a) 30% InFlow 2:1, 70% Water with Triton X-100

(b) 20% InFlow 2:1, 80% Water with Triton X-100

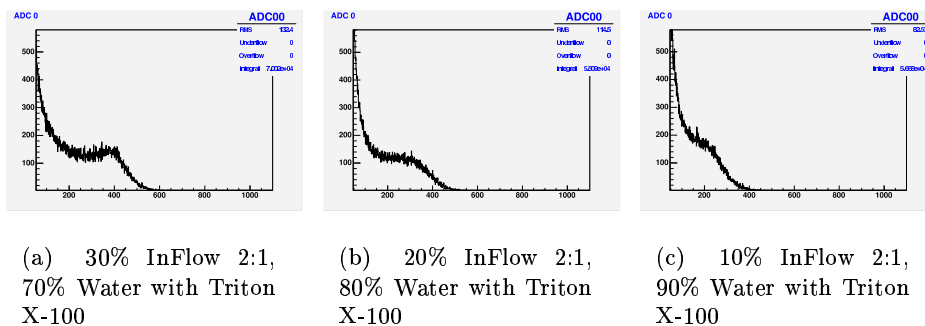(c) 10% InFlow 2:1, 90% Water with Triton X-100

Figure 7: Inflow 2:1 with Triton X-100 Spectra

The idea of water acting as a quencher was tested by keeping the concentration of scintillator the same while decreasing the amount of water and increasing the amount of surfactant. We found that a mixture of 20% scintillator, 30% surfactant and 50% water performed significantly better than a mixture of 20% scintillator and 80% water, suggesting that water is acting as a quencher [Fig:8].
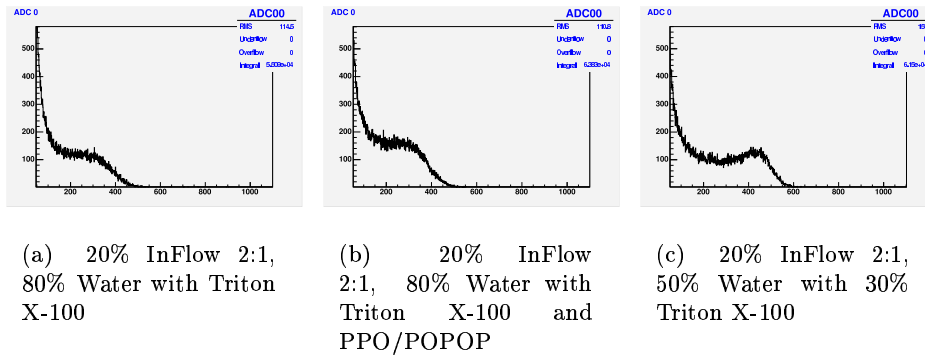

(a) 20% InFlow 2:1, 80% Water with Triton X-100

(b) 20% InFlow 2:1, 80% Water with Triton X-100 and PPO/POPOP

(c) 20% InFlow 2:1, 50% Water with 30% Triton X-100

Figure 8: 20% Inflow 2:1 Tests

3.2.2 QuickSafe A

QuickSafe A, sold by Zinsser, also contains a non-ionic surfactant for solubility but it uses di-isopropyl-naphthalene instead of 2-isopropyl xylene. Marketed as a Safe Scintillator [7], QuickSafe A has a flashpoint of over 150℃ and is biodegradable, making it safer to work with than InFlow 2:1 which has a flashpoint of only 52℃. QuickSafe A is supposed to form a stiff, transparent gel when mixed with water at a one to one ratio. Mixtures with higher water concentrations are supposed to form translucent gels while lower water concentrations will separate into two phases unsuitable for counting. Our mixtures of 50% QuickSafe did not form stiff gels and showed a separation into two liquid phases, one clear and the other white and opaque. We were able to achieve a stiff, relatively clear gel with 55% QuickSafe A and 45% water. This gel is highly temperature dependent and will lose its stiffness upon being handled extensively. It was found that heating or cooling the mixture resulted in a loss of transparency as the solution turned milky and opaque. When heated to 40℃, a 50% solution also showed separation into two distinct phases of clear liquid and viscous opaque gel.

Repeating the tests over time we noticed a general loss of sharpness of the Compton edge while at the same time an increase in the count rate. We made a solution that was 70% QuickSafe A and 30% water. This solution did not form a stiff gel but rather a slightly cloudy, viscous solution. We added 0.5ml of Triton X-100 to our 22ml sample and found the transparency and uniformity of the mixture improved. Upon adding another 0.5ml, this time of our Triton X-100/PPO/POPOP mixture, we noticed an increased number of absolute counts and observed a sharper Compton edge.
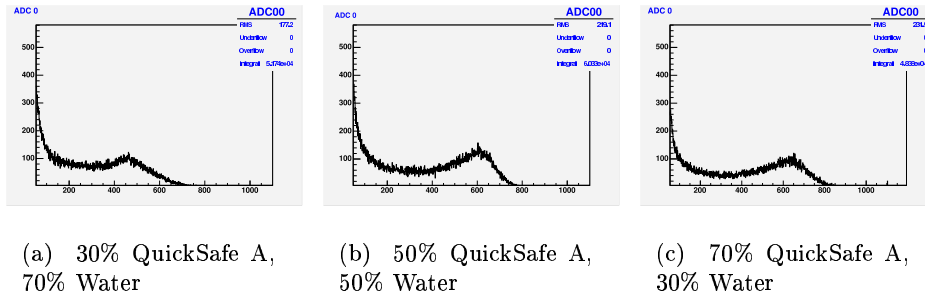

(a) 30% QuickSafe A, 70% Water

(b) 50% QuickSafe A, 50% Water

(c) 70% QuickSafe A, 30% Water

Figure 9: QuickSafe A Spectra

3.2.3 Gelling Agents

Every gelling agent we tried requires only a few percent by weight of the material to form a gel with water, which can be considered negligible contamination in a detector of this size. We tried both Knox and Robertson's brand gelatin which resulted in a uniform gel that is slightly yellow in colour although it is quite transparent. It is probable that this colour will mean it has poor transmission of wavelengths in the ultra-violet and blue regions. We tried Agar Agar which is a derivitive of seaweed and got a stiff gel that was slightly opaque and quite white in colour. Agarose powder is a refined version of Agar-Agar that is commonly used to make gel for electrophoresis. The Agarose gel was similar to the Agar-Agar gel in colour, transparency and stiffness. A third option was a Polyacrylate polymer. The brand we used was called Water Crystals and this mixture was full of air bubbles. Once it had been put under a vaccum pump for fifteen minutes the bubbles were gone and the gel was relatively transparent. Our best results for stiffness and transparency was with a Polyacrylamide polymer, also used for electrophoresis. This polymer, even though it is ideal for our purposes

in terms of transparency, cannot be used for the near detector because of the cost. This type of gel would be $300.00 for 2.5 litres, an unreasonable expense when such a large volume is needed [Appendix B].

Gelatin and Water Crystals initially seemed to be the two most promising alternatives to the expensive Polyacrylamide gel. When QuickSafe A or InFlow 2:1 was added to the gelatin, the mixture turned milky white and opaque. After time, there was a separation to a clear liquid phase on top of a white gel phase. Even when Triton X-100 was added so we started with a relatively clear scintillator and water mixture, the clarity was lost when mixed with the gelatin. Triton X-100 alone seemed enough to cause the gelatin mixture to be opaque. Similar results were found for Water Crystals. Initially quite transparent, once the scintillator was added the solution clouded over and eventually separated into a clear liquid and an opaque gel. The mixing also caused more air bubbles to be trapped in the gel and while vacuum pumping succeeded in eliminating the bubbles, the transparency didn't improve. We also tried two new gelling agents with the scintillators, Carrageenan powder and Klucel Hydropropylcellulose powder. The Klucel powder also produced an opaque, separated mixture but the Carrageenan powder produced an opaque but uniform gel.

3.3 WLS Fibres

This experiment is using wavelength shifting fibres, made of polystyrene and measuring one millimetre in diameter. To read out the light yield from the fibres while immersed in our liquid or gel scintillators we modified the cap of the commercial vials. Nine holes of 1.04mm diameter were drilled into the screw-on plastic cap of the vial in a uniform pattern using a number 59 drill bit. The WLS fibres are inserted tightly into the holes in such a way that they span the height of the vial and are sanded flush with the outside of the cap. The entire vial can then be inserted into the previously described apparatus with the cap and fibres in contact with the glass of the PMT [Fig:10].

The light collected by the PMT will therefore be coming only from the light travelling through the fibres and not through the opaque cap. To avoid the leaking of scinitllator through the cap, the entire apparatus is inverted so that the vial can be inserted upright and still have the cap and fibres facing the PMT. The vials are wrapped in aluminized mylar for these tests as well. QuickSafe A and InFlow 2:1 performed equally as well with the specially designed vials; our aging test will be done with QuickSafe A since it is safer to work with.
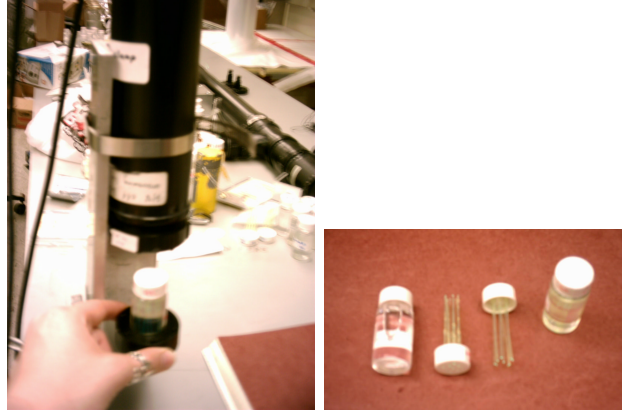
(a) Loading Vials Upright into PMT Tube

(b) Caps with fibres

Figure 10: Fibres and Inverted Apparatus

The ends of the fibre within the vial are also sanded flat. Originally, these ends were covered with aluminized mylar which would reflect any light travelling down the fibre back up and towards the photomultiplier tube. These mylar ends increased the light yield by 50%, however, they were attached with optical cement and it was found that the cement is slowly corroded in the water-scintillator solution, causing the reflective ends to fall off. It is known that polystyrene can degrade when left in contact with the components of QuickSafe A. Because the 280m near detector will be in operation for such a long duration, we need to determine how quickly and to what extent the fibre is damaged in time. The light yield observed without the reflective ends is sufficient for conducting aging tests and not having them will allow us to differentiate between a loss of light yield from damaging or aging of the fibres with the loss of light yield as a result of the disintegrating mylar.

The idea of the aging test is straightforward. To determine if the fibre is damaged by the scintillator, three samples of 100% QuickSafe A Liquid Scintillator were prepared, each with its own cap of nine polished WLS fibres distributed fairly uniformly throughout the volume of the vial. The nine fibres of one set were coated in optical grease, another with optical cement and the third left bare. The idea is that the coated fibres may show resistance to any damage caused by direct exposure of the scintillator

to the coating of the fibre. Before the fibres were actually inserted into the samples, a five minute direct reading of the scintillator exposed to the Co-60 source was done for each of the three samples as well as a fourth reference sample. The reference sample did not have fibres put in it and was stored under the same conditions as the other three. There is consistantly an increase in the number of counts observed for the first three or four runs done on each individual sample. The cause of this systematic error is not completely understood but thought to be a result of turning off the high-voltage supply in order to replace the current sample. To overcome this problem, each direct measurement is repeated until three consecutive runs provide a relatively constant number of counts, also paying attention to any significant changes in the shape of the observed Compton edge.

After the initial direct readings, the fibres are inserted into their respective samples and the light yield through the fibres is measured in the same manner for each, repeated until three consistant runs are achieved. The samples are then left for one week, and the tests are repeated. The fibres are removed for direct readings of the scintillator alone, replaced so the light yield through the fibres can be measured and then a third trial is done where the three sets of aged fibres are placed in a fresh sample of QuickSafe A that has not previously had fibres in it. This procedure is repeated on a weekly basis and the data sets from each week can be compared to look for obvious changes and patterns.

4   Conclusions

For the purposes of the 280m near detector, both InFlow 2:1 and QuickSafe A could be used as liquid scintillator. Either option allows for a water concentration of up to 70% while maintaining sufficient light output to be useful. The addition of Triton X-100 allows for even better performance and stability of the solutions. QuickSafe A is perhaps a better choice because it is safer to work with and showed slightly better results when mixed with Triton X-100 than InFlow 2:1.

As far as finding a suitable gel medium, no suitable gels were formed with InFlow 2:1. Our best option so far is to use Carrageenan powder with some concentration of QuickSafe A. When a gel was made with a 20% QuickSafe A and 80% water mixture the counting efficiency was roughly the same as with just the scintillator and water even though it does not look as transparent and the Compton edge is not clearly recognizable in either case [Fig:12]. Another option would be to use a mixture of 55% QuickSafe A and

(a) Fibre in Scintillator
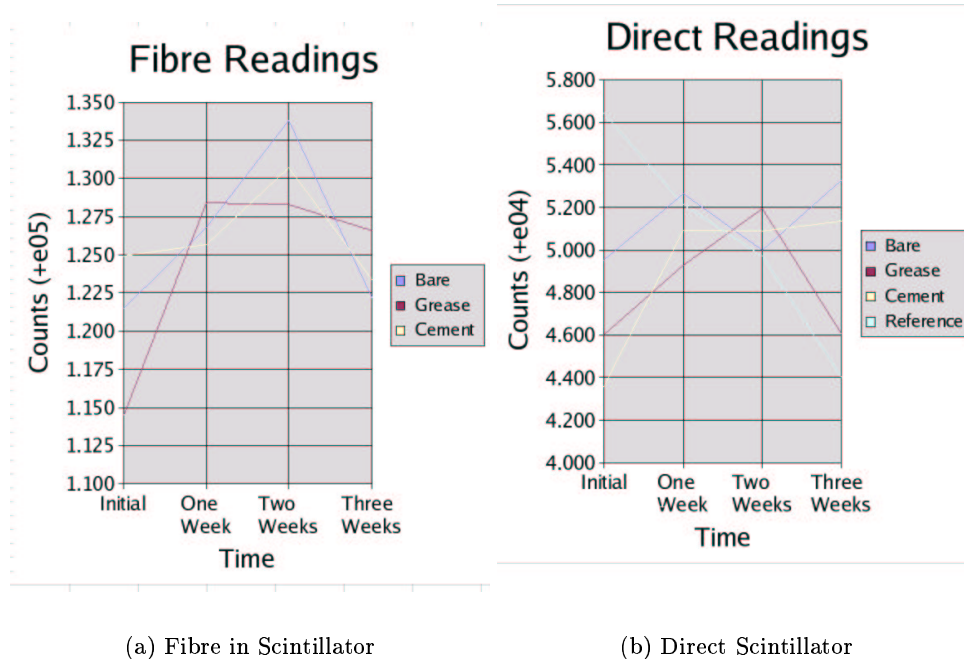
(b) Direct Scintillator

Figure 11: Age Test Plots

45% water. Further research can be done to attempt to find a suitable gel medium while maintaining the high water concentrations.

The aging test has been inconclusive and further time must be put into determining the effects. It seems as though the efficiency of the fibres increased over the first two weeks of trials and has started to drop off after the third week [Fig:11a]. The cause for this is unknown and the results might be misleading since the scintillator itself seems to undergo a change when left in contact with the fibres. Unexpectedly, when measuring the scinillation light of the QuickSafe A directly, without WLS fibres, the absolute number of counts observed varied between our reference sample and the other three vials [Fig:11b]. Progress has been made in differentiating between changes to the scintillator itself as well as the performance and properties of the fibres. No clear pattern has emerged but more data will help in clarifying what is actualy happening and improvements are being made to the experimental technique as we discover problems.

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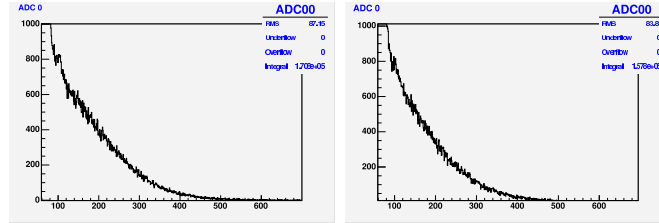
(a) 20% QuickSafe A with Triton X-100

(b) 20% QuickSafe A with 1% Carrageenan Powder

Figure 12: Gel Test Plots

4.1   Recommendations

Several new gelling agents have been ordered for testing including water soluble vinyl polyers called Carbomers and a thickener called Aculyn. Similar tests mixing the gels with a liquid scintillator will be done. More research will be done into the chemical properties of both the scintillators and gelling agents as well as their reactions to each other.

The aging tests will continue in the hope that more data points will provide a clearer picture of what is happening. Several different methods of determining the aging effects will be tried as well. A section of the WLS fibre will be examined under a microscope and weighed to high precision. The fibre will then be left in the liquid scintillator for a period of time after which the fibre can be removed, reexamined for visible damage to the coating as well as weighed again to determine if there was any loss of mass not noticable to the naked eye. The WLS fibre dissolving in the scintillator could account for some of the unsual results found with direct readings of the QuickSafe A. Aging tests similar to the one currently underway can be done using a beam of electrons from the Cyclotron instead of a Cobalt-60 source. Beam tests will provide more easily analyzed data because we will be able to observe a single sharp peak rather than only half of a peak.
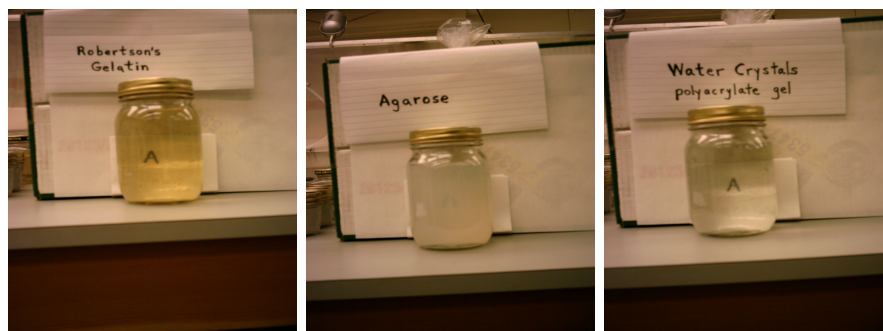
5 Appendices

A Aluminized Mylar Effects
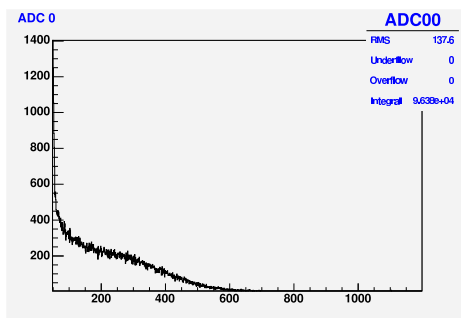
(a) 100% QuickSafe A without Aluminized Mylar around bottom of vial
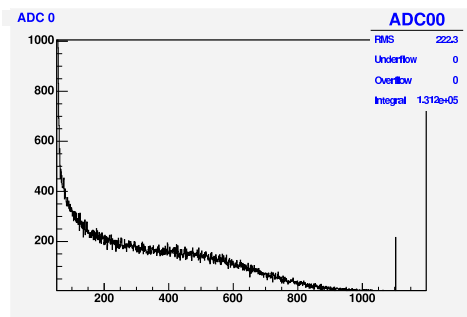
(b) 100% QuickSafe A with Aluminized Mylar around whole vial
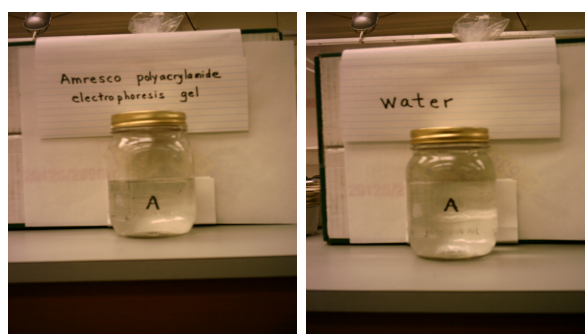
Figure 13: Aluminized Mylar Effects

B   Gel Test Photos

(a) Gelatin

(b) Agarose Electrophoresis Gel

(c) Water Crystals Polyacrylate Gel

(d) Polyacrylamide Electrophoresis Gel

(e) Water for Comparison

Figure 14: Gel Transparency and Colour

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